ACID BASE MANAGEMENT IN EMERGENCY CARE

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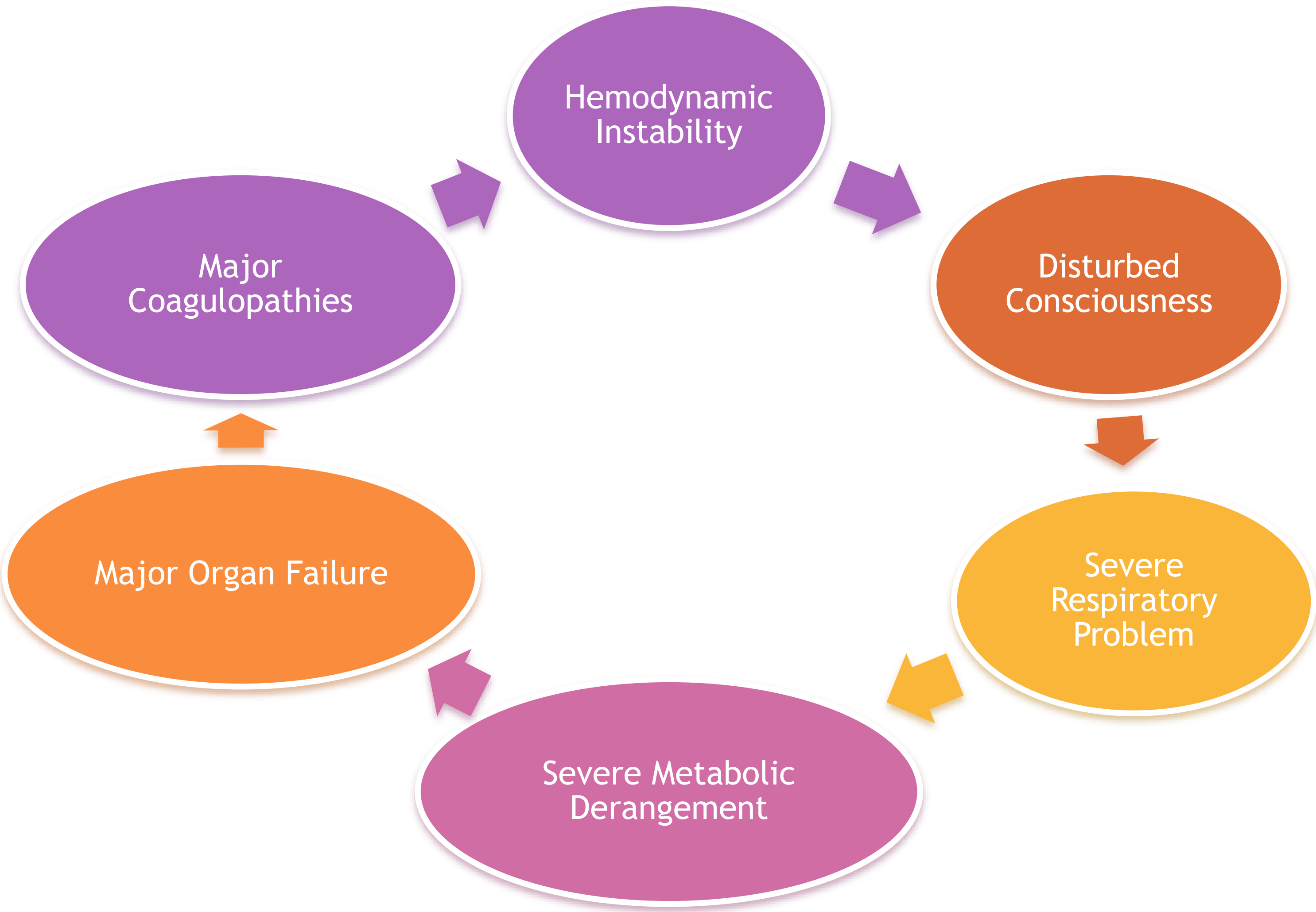
MEDICAL CRITICAL-ILLNESS



Example Case

- An 84-year-old female nursing home resident is brought to the A/E due to lethargy. At the nursing home, she was found to have a BP of 85/60 mmHg, HR 101 beats/min, temp. 37.8°C. Lab: Na 137 meq/L, K 2.8 meq/L, [HCO_3^-] 8 meq/L, Cl 117 meq/L, BUN 17 mg/dL, creatinine 0.9 mg/dL. An ABG shows PaO_2 80 mmHg, PCO_2 24 mmHg, pH 7.29. Her urine analysis is clear and has a pH of 4.5. What is the acid-base disorder?
  - A. Anion-gap metabolic acidosis
  - B. Non-anion gap metabolic acidosis
  - C. Non-anion-gap metabolic acidosis and respiratory alkalosis
  - D. Respiratory acidosis

Acids-Bases Characteristics

Acids (Properties)

- Taste Sour
- Turn Blue litmus Red
- Neutralizes bases
- Reacts with metals
- pH below 7

Examples:

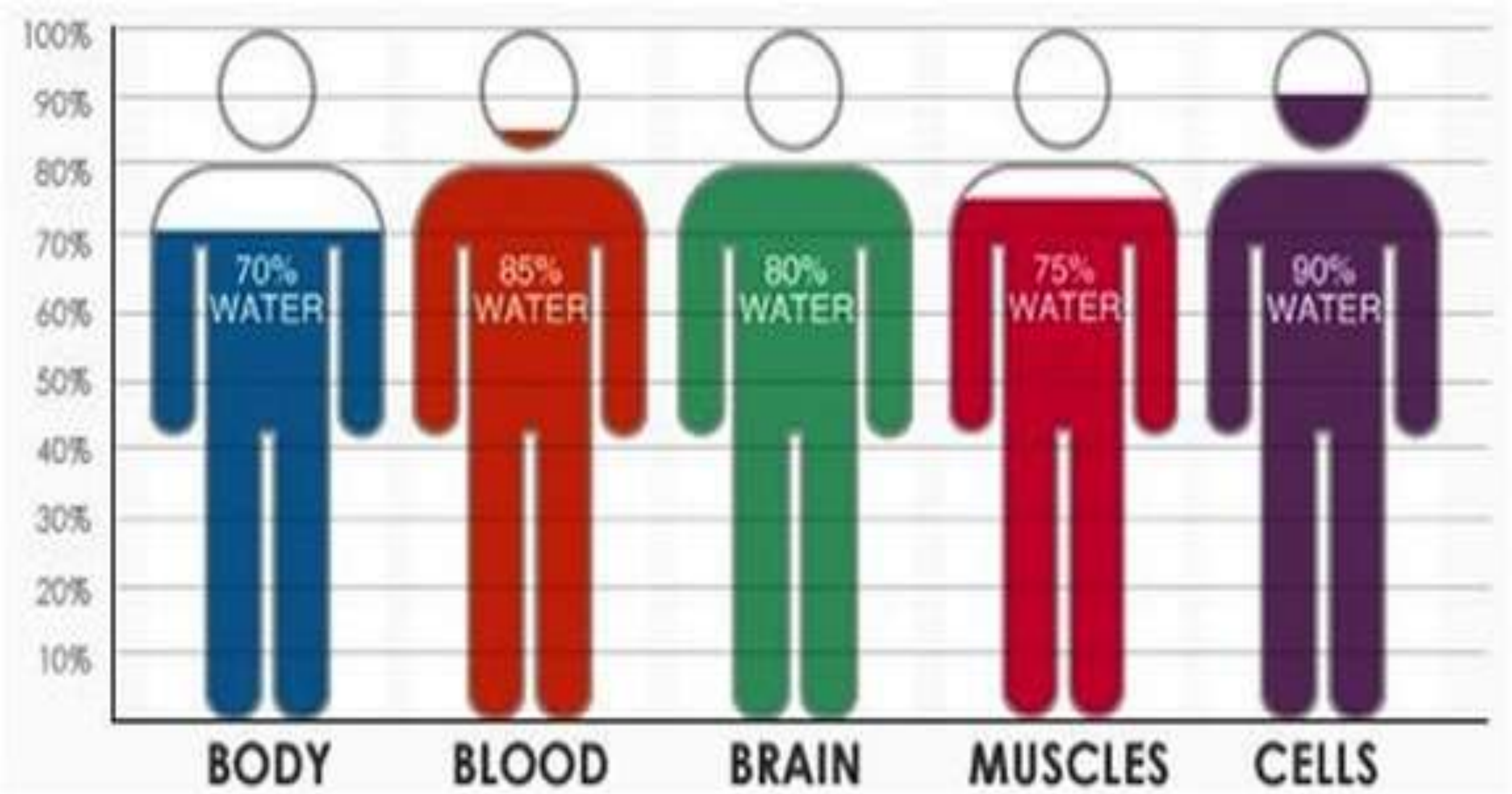
- Juices: Tomato, Orange, Grapefruit
- Wine
- Banana
- Coffee
- Vitamin C
- Soda

Base (Properties)

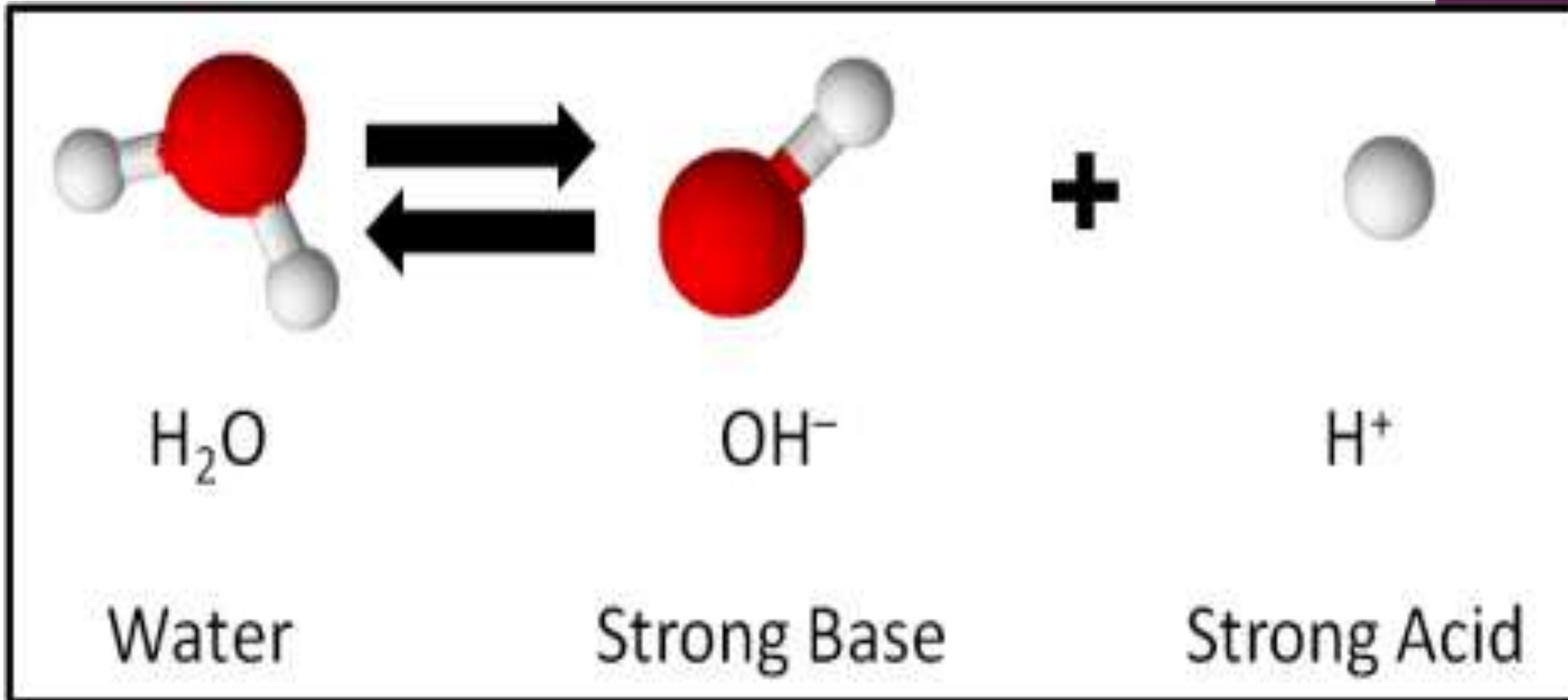
- Taste Bitter
- Turns Red litmus Blue
- Neutralizes acids
- Turns metal into hydroxides
- pH above 7
- Slippery

Examples:

- Milk of Magnesia
- Lime water
- Lye, Draino
- Ammonia
- blood
- Soap



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
70% WATER
85% WATER
80% WATER
75% WATER
90% WATER
BODY
BLOOD
BRAIN
MUSCLES
CELLS



H_2O
OH^-
H^+
Water
Strong Base
Strong Acid

For dissociation of water,

$$H_2O + H_2O \rightarrow H_3O^+ + OH^-$$

$$K = \frac{[H^+][OH^-]}{[H_2O]}$$

Since one mole (mol) of water weighs 18 g, one liter (L) (1000 g) of water contains 1000 . 18 =55.56 mol. Pure water thus is 55.56 molar. Since the probability that a hydrogen in pure water will exist as a hydrogen ion is $1.8X10^{-9}$, the molar concentration of H+ ions (or of OH− ions) in pure water is the product of the probability, $1.8 X 10^{-9}$, times the molar oncentration of water, 55.56 mol/L. The result is $1.0X10^{-7}$ mol/L

We can now calculate K for water:

$$K = \frac{[H^+][OH^-]}{[H_2O]} = \frac{[10^{-7}][10^{-7}]}{[55.56]}$$

$$= 0.018 \times 10^{-14} = 1.8 \times 10^{-16} \text{ mol/L}$$

$$K = \frac{[H^+][OH^-]}{[H_2O]} = 1.8 \times 10^{-16} \text{ mol/L}$$

$$K_w = (K)[H_2O] = [H^+][OH^-]$$

$$= (1.8 \times 10^{-16} \text{ mol/L})\,(55.56 \text{ mol/L})$$

$$= 1.00 \times 10^{-14} \text{ (mol/L)}^2$$

For example, for pure water at 25°C,

$$pH = -\log [H^+] = -\log 10^{-7} = -(-7) = 7.0$$

Hydrogen Ion (H^+)

- Maintenance of [H^+] in the body within narrow limits is very crucial for normal cell function.

- [H^+] is very reactive, particularly with the –vely charged protein molecules, thus affecting activity and functions of enzymes and other proteins

- Proteins lose or gain H^+ according to plasma [H^+].

- Normally the plasma [H^+] is very low: 40 nanoEq/L i.e 40 X 10^{-9} mol/L; this is roughly one millionth the mEq/L concentrations of Na, K, and Cl

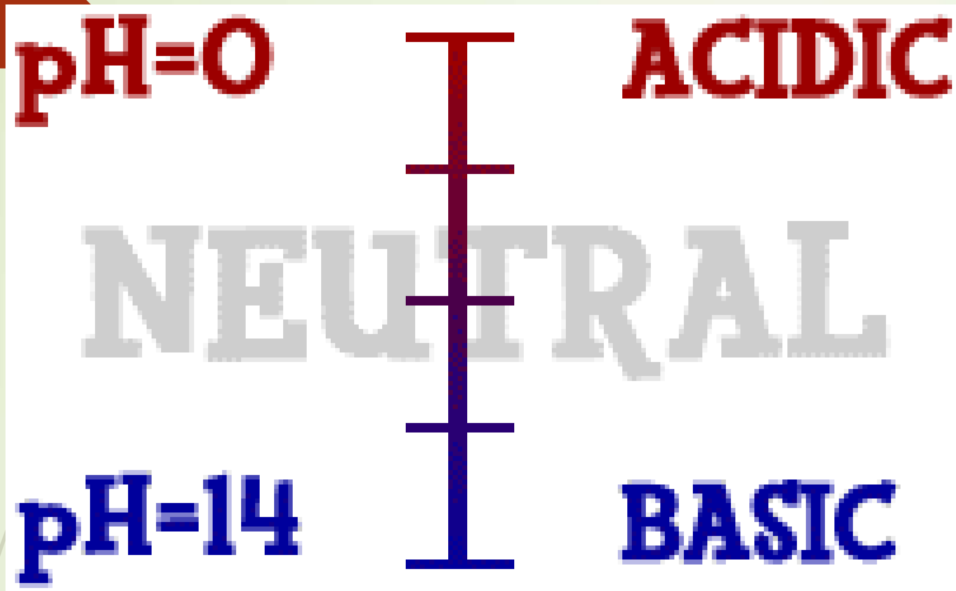
- Buffering systems exist in the body to limit change of [H^+] after addition or removal of H^+

H^+ i.e PROTON

- The smallest particle
- Highly reactive espec. With –ve charged proteins
- Proteins may accept or donate H^+ to limited degree without much change in structure or function
- Out of limit change of H^+ content of proteins may cause serious change in function up to denaturation of proteins
- Structure proteins, transporters and enzymes are especially vulnerable

- Acid - increases H^+ (H_3O^+) concentration
- Bases - increases OH^- concentration
- Acids are substances that are able to ionize to form hydrogen ions and thereby increase the concentration of $H^+(aq)$ ions in aqueous solutions.
- $$H_2SO_{4\,(aq)} \longrightarrow H^+_{(aq)} + HSO_4^-{}_{(aq)}$$
- Bases are substances that accept (react with) H^+ ions. Hydroxide ions, OH^-, an ion which readily react with H^+ ions to form water:
- $$H^+_{(aq)} + OH^-_{(aq)} \longrightarrow H_2O_{(l)}$$

pH (power of Hydrogen)



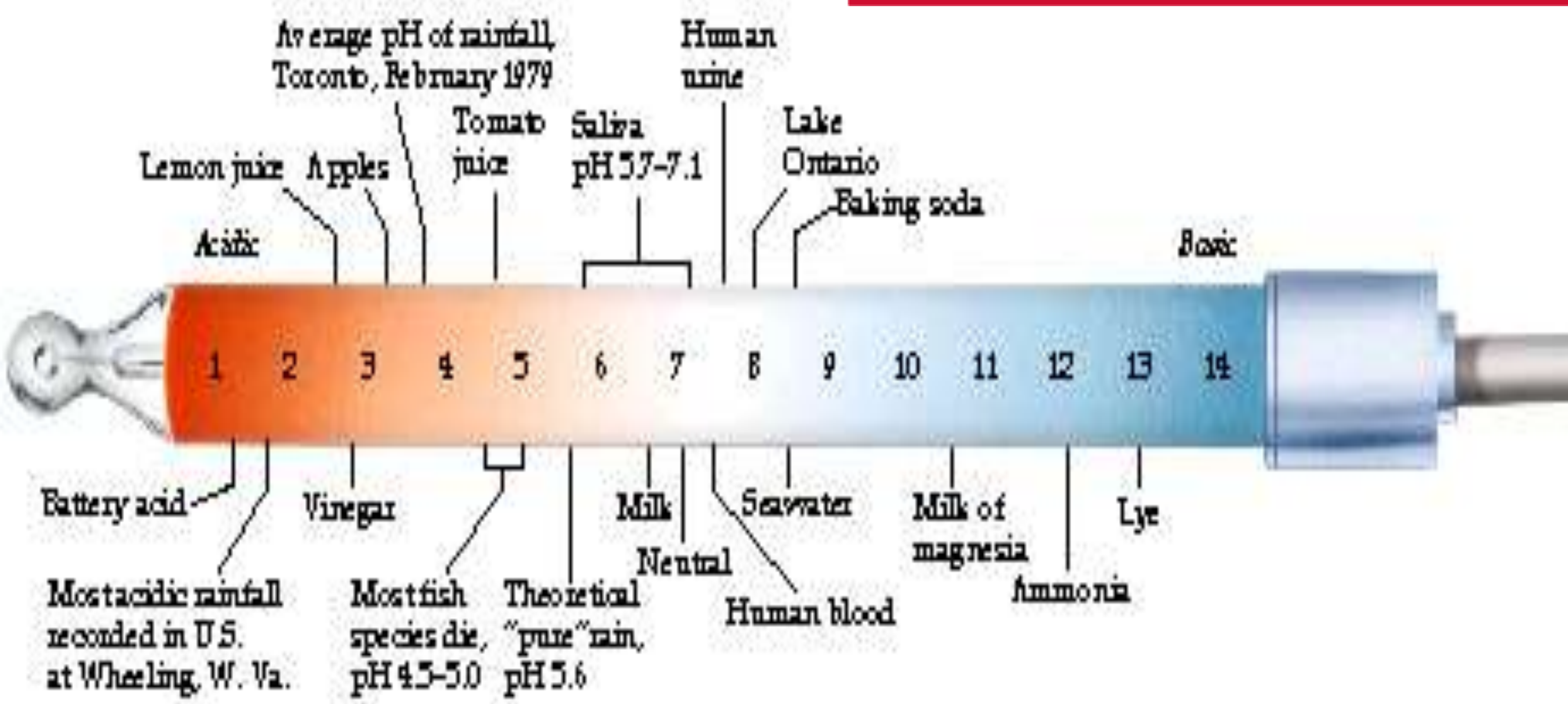
Scientists use the "**pH**" scale to measure how acidic or basic a liquid is. pH is a measure of the concentration of hydrogen ions (protons) per liter The scale goes from "0" to "14". Distilled water (pure water) is 7 (right in the middle). Acids are found between "0" and "7". Bases are from "7" to "14".

pH values

- pH Values for various samples:

- Acid: pH : 1 -- 6
- Neutral: pH 7
- Base: pH 8 -- 14

• Smaller the pH value the greater the acidity
• larger the pH value the lower the acidity



As the molar conc. of $[H^+]$ in ECF is very low: 0.00000004 mol/L, it is conventionally expressed as the negative logarithmic value

$pH = -\log[H^+]$ & $[H^+] = 10^{-pH}$

Normal $pH = -\log(0.00000004) = 7.40$

PH units	[H+] nmol/L	PH units	[H+] nmol/L	PH units	[H+] nmol/L
6.90	126	7.32	48	7.48	33
7.00	100	7.35	45	7.51	31
7.10	79	7.37	43	7.53	30
7.20	63	7.39	41	7.55	28
7.22	60	7.40	40	7.58	26
7.25	56	7.42	38	7.60	25
7.28	52	7.44	36	7.65	22
7.30	50	7.45	35	7.70	20

If pH () 7.25-7.45 $[H^+]$ = 80 - the decimal of pH

Acids & Bases – 1

- Acid: a substance that can donate H^{+}; Base: a substance that can accept H^{+}

- Physiologically important acids are in 2 classes:
  CARBONIC ACID & NONCARBONIC ACIDS

- The importance of carbonic acid (H_2CO_3):

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

15000 mmol/day CO_2 is generated from the metabolism of CHO & fats. Unless it is disposed through the lungs, CO_2 would cause enormous accumulation of acid

Acids & Bases – 2

- The noncarbonic acids are produced from the metabolism of aminoacids & breakdown of proteins in a rate of only <u>50-100 mEq/day</u>

- The average adult produces <u>10000-15000 mEq H^+/day</u>; 99% excreted via the lungs & 1% via the kidneys

- In other words, a normal western diet: results in the net production of 50-100 mEq of H^+/day

Hederson-Hasselbalch Equation

$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

$[H^+] = K_{eq} \times [H_2CO_3]/[HCO_3^-]$

$[H^+] = K \times [\alpha CO_2]/[HCO_3^-]$ *(Henderson, 1909)*

(α = solubility of CO_2 in physiologic solutions = 0.03)

$pH = pK + \log([HCO_3^-)/[\alpha CO_2])$ *(Hasselbalch, 1916)*

$\therefore\ pH = 6.111 + \log([HCO_3^-]/[0.03PCO_2])$

And since log 0.03 = -1.5228787

$\therefore\ pH = 7.632 + \log([HCO_3^-]/PCO_2)$

Buffering – 1

- If 80 mEq H^+ were distributed in the 40 L of TBW, the $[H^+]$ would increase by $2x10^6$ nanoEq/L; ~10^6 times normal,

- giving pH value = (-log ($2X10^{-3}$) = 2.7) that is incompatible with life

- Body buffers: HCO_3^- in ECF, HPO_4^{2-} & protein anions in cells and PO_3^{2-} in bone - prevent this by binding the H^+

Buffering – 2

- $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
- Adding 2 mEq H^+ will cause shift to the left; thus ↓ HCO_3^- by 2 & ↑ CO_2 by 2 mEq (↑P_{CO2} from 40 to 40+(2/0.03)= 107 mmHg)
- $pH=6.11+\log([HCO_3^-]/0.03XP_{CO2})$
- $= \log(22/0.03X107)=6.95$
- This is much better than the pH=2.7 without buffering

Acidemia & Alkalemia *vs.* Acidosis & Alkalosis

When acids or alkalis are added to ECF the body tries to nullify pH changes by <u>buffers</u>, <u>respiratory</u> compensatory efforts & by <u>renal and metabolic</u> compensatory efforts

- **<u>Acidemia</u> = reduction of pH or elevation of [H^+] of the ECF**
- **<u>Alkalemia</u> = elevation of pH or reduction of [H^+] of the ECF**

- **<u>Acidosis</u> = the pathophysiological process or condition that tends to lead to acidemia even if not yet associated with reduction of pH or elevation of [H^+] of the ECF**
- **<u>Alkalosis</u> = the pathophysiological process or condition that tends to lead to aklakemia even if not yet associated with elevation of pH or reduction of [H^+] of the ECF**

The Bicarbonate-Carbon Dioxide System

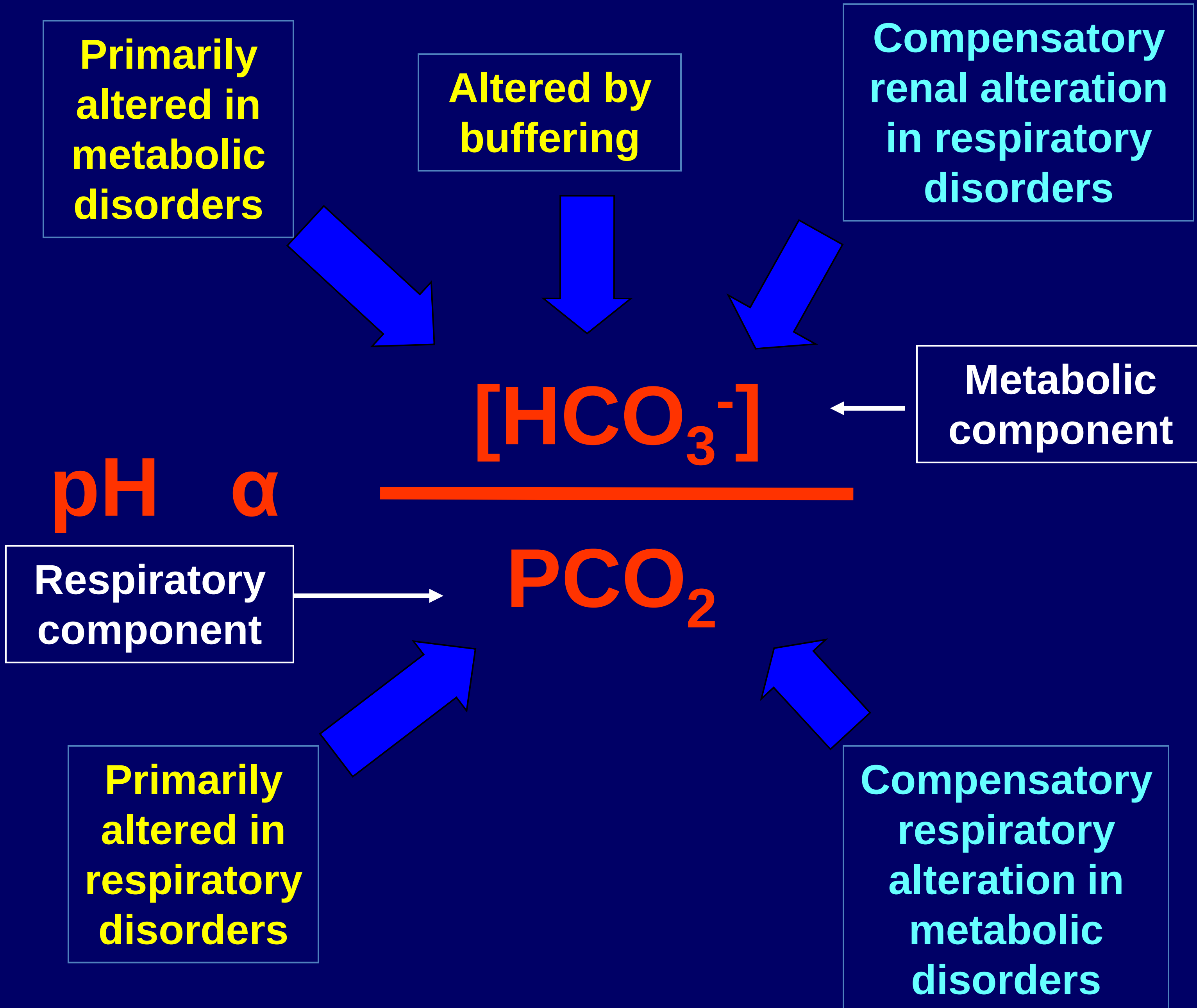
$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

Pulmonary component (CO_2)

Metabolic component (HCO_3^-)

$$pH = 6.11 + \log([HCO_3^-] / 0.03 \times PCO_2)$$

- **↑ pH (alkalemia) can result either from: ↑ HCO_3^- or ↓ P_{CO2}**
- **↓ pH (acidemia) can result either from: ↓ HCO_3^- or ↑ P_{CO2}**


Primarily altered in metabolic disorders
Altered by buffering
Compensatory renal alteration in respiratory disorders
Metabolic component
$pH \;\alpha\; \frac{[HCO_3^-]}{PCO_2}$
Respiratory component
Primarily altered in respiratory disorders
Compensatory respiratory alteration in metabolic disorders

$$\downarrow \text{pH} \quad \alpha \quad \frac{[HCO_3^-]\downarrow}{\downarrow PCO_2}$$

Metabolic Acidosis

$$\uparrow \; pH \;\; \alpha \;\; \frac{\downarrow [HCO_3^-]}{PCO_2 \downarrow}$$

Respiratory Alkalosis

$$\downarrow \mathrm{pH} \quad \alpha \quad \frac{\uparrow [HCO_3^-]}{PCO_2 \uparrow}$$

Respiratory Acidosis

$$\uparrow pH \; \alpha \; \frac{\uparrow [HCO_3^-]}{\uparrow PCO_2}$$

Metabolic Alkalosis

Primary & Compensatory Responses -1

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

Respiratory

Primary Response		Compensatory Response
$\uparrow CO_2$	$\rightarrow$	$\uparrow HCO_3^-$
$\downarrow CO_2$	$\rightarrow$	$\downarrow HCO_3^-$

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

Metabolic

Compensatory Response		Primary Response
$\uparrow CO_2$	$\leftarrow$	$\uparrow HCO_3^-$
$\downarrow CO_2$	$\leftarrow$	$\downarrow HCO_3^-$

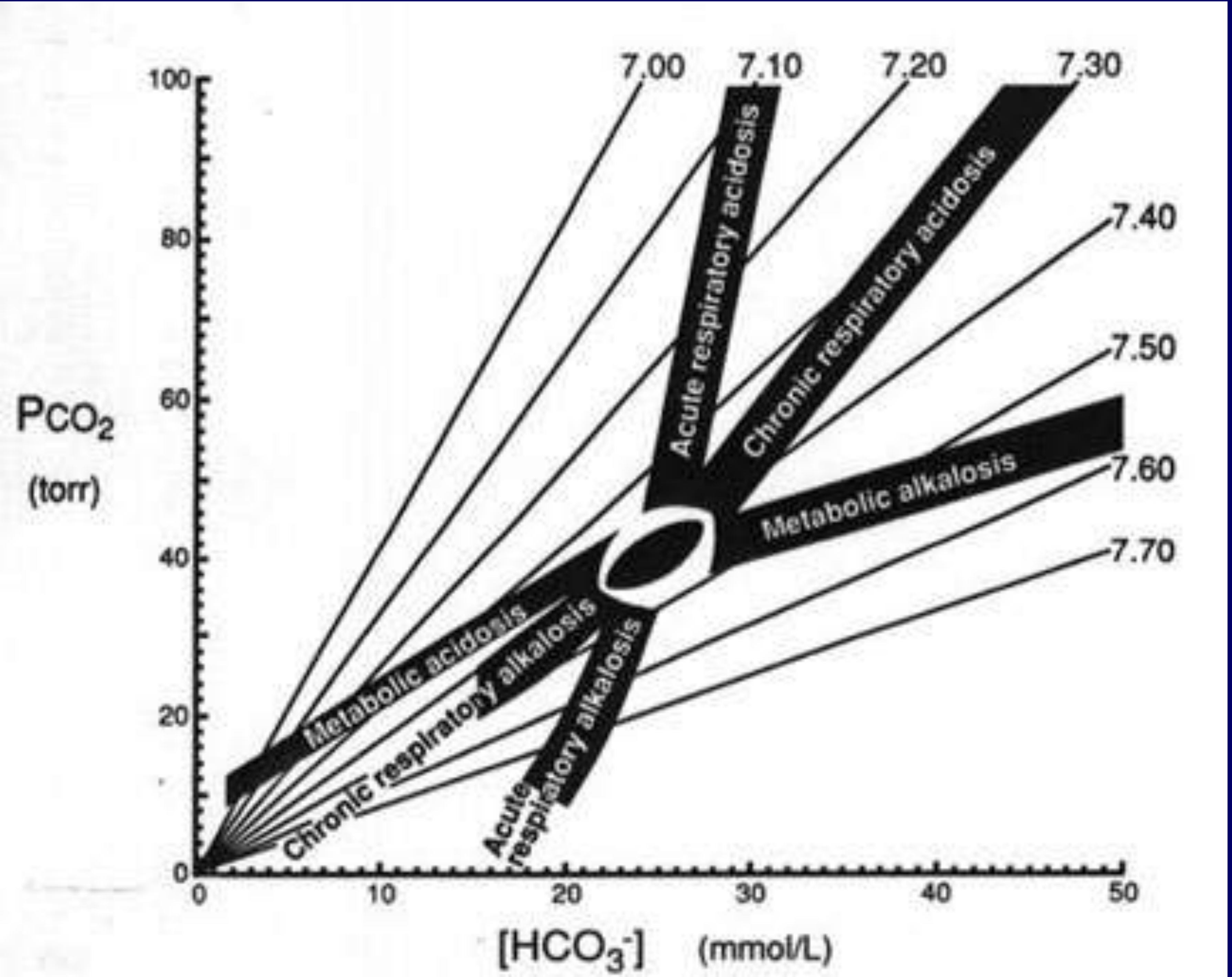
Primary & Compensatory Responses -2

$[H^+]$	pH	HCO_3^-	PCO_2	
↑	↓	↓	↓	**Metabolic Acidosis**
↑	↓	↑	↑	**Respiratory Acidosis**
↓	↑	↑	↑	**Metabolic Alkalosis**
↓	↑	↓	↓	**Respiratory Alkalosis**

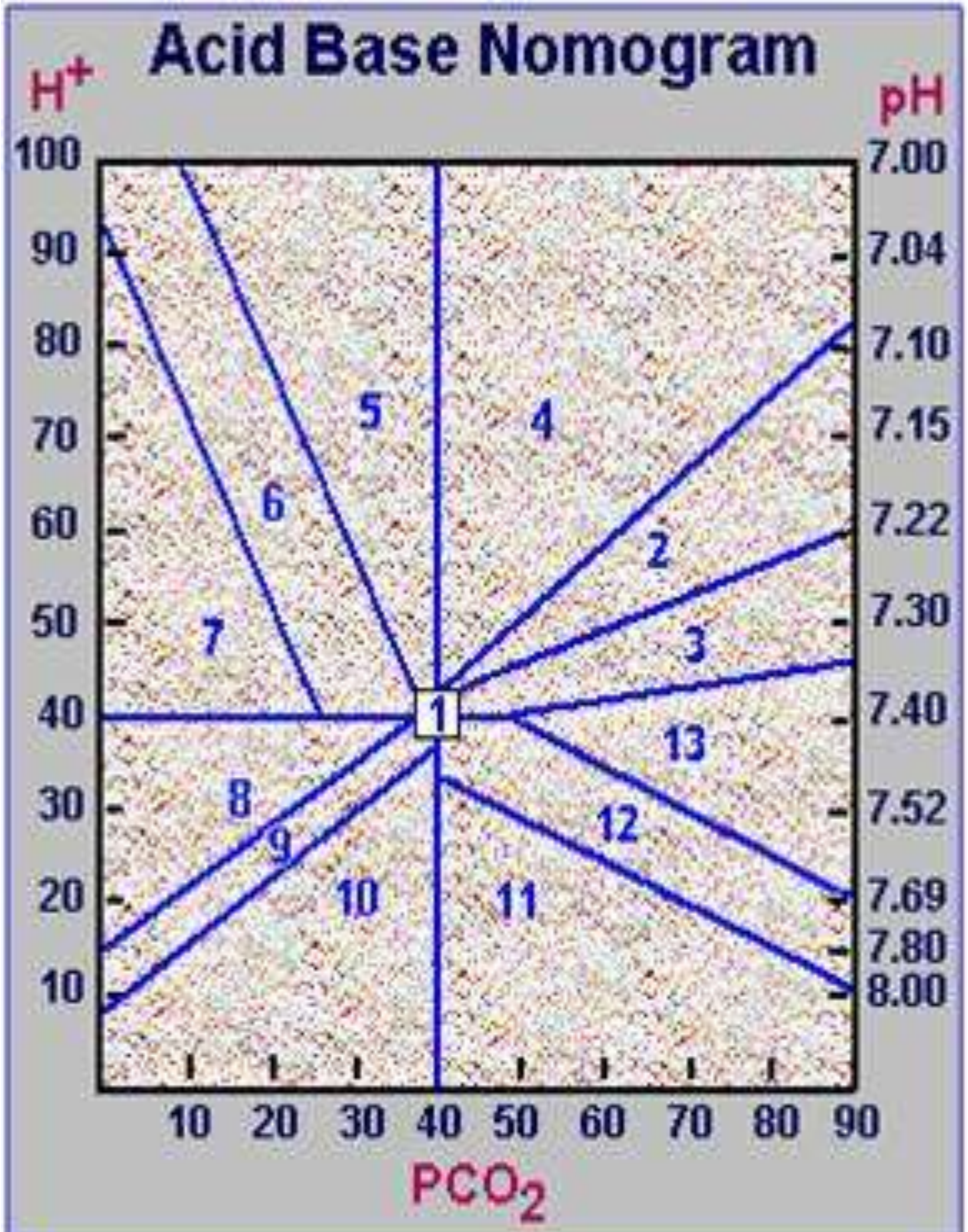
Is there appropriate compensation for the 1ry disturbance?

Usually, compensation does ***not*** return the pH to normal (7.35 – 7.45).

Disorder	Expected compensation	Correctf actor
Metabolic acidosis	$PaCO_2 = (1.5 \times [HCO_3^-]) + 8$	± 2
Acute respiratory acidosis	Increase in $[HCO_3^-] = \Delta\ PaCO_2/10$	± 3
Chronic respiratory acidosis (3-5 days)	Increase in $[HCO_3^-] = 3.5(\Delta\ PaCO_2/10)$	
Metabolic alkalosis	Expected $PaCO_2 = 40 + 0.6(\Delta HCO_3^-)$	
Acute respiratory alkalosis	Decrease in $[HCO_3^-] = 2(\Delta\ PaCO_2/10)$	
Chronic respiratory alkalosis	Decrease in $[HCO_3^-] = 5(\Delta\ PaCO_2/10)$ to $7(\Delta\ PaCO_2/10)$	



7.00
7.10
7.20
7.30
7.40
7.50
7.60
7.70
Acute respiratory acidosis
Chronic respiratory acidosis
Metabolic alkalosis
Metabolic acidosis
Chronic respiratory alkalosis
Acute respiratory alkalosis
PCO2
(torr)
100
80
60
40
20
0
10
20
30
40
50
[HCO3-] (mmol/L)



Acid Base Nomogram
H+
pH
100
90
80
70
60
50
40
30
20
10
7.00
7.04
7.10
7.15
7.22
7.30
7.40
7.52
7.69
7.80
8.00
1
2
3
4
5
6
7
8
9
10
11
12
13
10 20 30 40 50 60 70 80 90
PCO2

6-step approach

- **Step 1:** Assess the internal consistency of the values using the Henderseon-Hasselbach equation: $[H+] = \dfrac{24(PaCO_2)}{[HCO_3-]}$
  - Or $pH = 7.623 + \log([HCO_3^-]/PCO_2)$
- **Step 2:** Is there alkalemia or acidemia present?
  - pH < 7.35 acidemia, pH > 7.45 alkalemia
  - *Remember:* an acidosis or alkalosis may be present even if the pH is in the normal range (7.35 – 7.45)
  - You will need to check the $PaCO_2$, HCO_3- and anion gap
- **Step 3:** Is the disturbance respiratory or metabolic?
- **Step 4:** Is there appropriate compensation for the primary disturbance? Usually, compensation does <u>not</u> return the pH to normal (7.35 – 7.45).
- **Step 5:** Calculate the anion gap (if a metabolic acidosis exists)
- **Step 6:** If an increased anion gap is present, assess the relationship between the increase in the anion gap and the decrease in $[HCO_3-]$.

Clinical Manifestations of Altered pH & PCO2

Acidemia:

Depressed sensorium

Depressed myocardial squeeze

Alkalemia:

Tetany; Seizures; muscle weakness

Ventricular arrhythmias

Hypercapnia:

Headache; papilledema; astrexis

Hypocapnia:

Coronary spasm; Electrocardiogram ST segment elevation

Clinical Manifestations due to Underlying Causes of Acid-Base Disorders

Signs & Symptoms	Suspected Acid-Base Disorders
Central Nervous System	
Coma	Respiratory Acidosis or Alkalosis
Seizures	Metabolic Acidosis
Cardiovascular System	
Congestive Heart Failure	Respiratory Alkalosis
Shock	Metabolic Acidosis
Respiratory System	
Tachypnea, Hyperpnea	Respiratory Alkalosis
Bradypnea, Hypopnea	Respiratory Acidosis
Gastrointestinal System	
Vomiting	Metabolic Alkalosis
Diarrhea	Metabolic Acidosis
Abdominal Pain	Repiratory Alkalosis
Renal Excretory System	
Oliguria, Anuria	Metabolic Acidosis
Diuretics' Polyuria	Metabolic Alkalosis
DKA Polyuria	Metabolic Acidosis
Endocrine System	
Myxedema	Respiratory Acidosis
Htn (Conn's or Cushing's)	Metabolic Alkalosis

Laboratory Markers of Acid-Base Disorders

Laboratory Variable	Disorder
Serum Bicarbonate HCO_3	
Increased	Metabolic alkalosis or respiratory acidosis
Decreased	Metabolic acidosis or respiratory alkalosis
Serum Potassium	
Increased	Hyperkalemic distal renal tubular acidosis
Decreased	Metabolic alkalosis, or renal tubular acidosis
Serum Anion Gap	
Increased Markedly	Organic acidosis
$AG - 9 = tCO_2 > 27$	Metabolic alkalosis

Normal Values of Acid-Base Variables at Sea Level & 37C

$[H^+]$ arterial (nmol/L)	40 (37 – 43)
PH arterial	7.40 (7.37 – 7.43)
PCO_2 arterial (mmHg)	40 (37 – 43)
HCO_3^- arterial (mmol/L)	24 (22 – 26)
Total CO_2 venous (mmol/L)	28 (26 – 30)
Anion Gap venous	12 (8 – 16)

Primary & Compensatory Responses -b

	$[H^+]$	pH	1ry Change	Compensatory Response
Metabolic Acidosis	↑	↓	$\downarrow HCO_3^-$	$\downarrow PCO_2$ $\Delta PCO_2 = 1.2\ \Delta HCO_3^-$
Respiratory Acidosis	↑	↓	$\uparrow PCO_2$	$\uparrow HCO_3^-$ Acute: $\Delta HCO_3^- = 0.1\ \Delta PCO_2$ Chronic: $\Delta HCO_3^- = 0.4\ \Delta PCO_2$
Metabolic Alkalosis	↓	↑	$\uparrow HCO_3^-$	$\uparrow PCO_2$ $\Delta PCO_2 = 0.6\ \Delta HCO_3^-$
Respiratory Alkalosis	↓	↑	$\downarrow PCO_2$	$\downarrow HCO_3^-$ Acute: $\Delta HCO_3^- = 0.2\ \Delta PCO_2$ Chronic: $\Delta HCO_3^- = 0.4\ \Delta PCO_2$

Acid-Base Disorders: Simple or Mixed

- **Simple: 2ry compensatory response is appropriate in direction and magnitude to the 1ry effect**
- **Mixed: 2ry compensatory response is either more or less than expected from the 1ry effect**

- Metab. Acidosis + Resp. Alkalosis:
  ΔPCO_2 > 1.5 times ΔHCO_3^-; pH no much change
- Metab. Acidosis + Resp. Acidosis:
  ΔPCO_2 < 1.0 times ΔHCO_3^-; pH so much ↓ed
- Metab. Alkalosis + Resp. Acidosis:
  ΔPCO_2 >1.0 times ΔHCO_3^-; pH no much change
- Metab. Alkalosis + Resp. Alkalosis:
  ΔPCO_2 < 0.25 times ΔHCO_3^-; pH so much ↑ed

Acid-Base Disorders: Mixed Metabolic Disorders

- Metabolic acidosis + metabolic alkalosis
- High anion gap acidosis + hyperchloremic acidosis
- Mixed anion gap acidosis
- Mixed hyperchloremic acidosis

Triple Acid-Base Disorders

- Metabolic acidosis + metabolic alkalosis + respiratory acidosis
- Metabolic acidosis + metabolic alkalosis + respiratory alkalosis

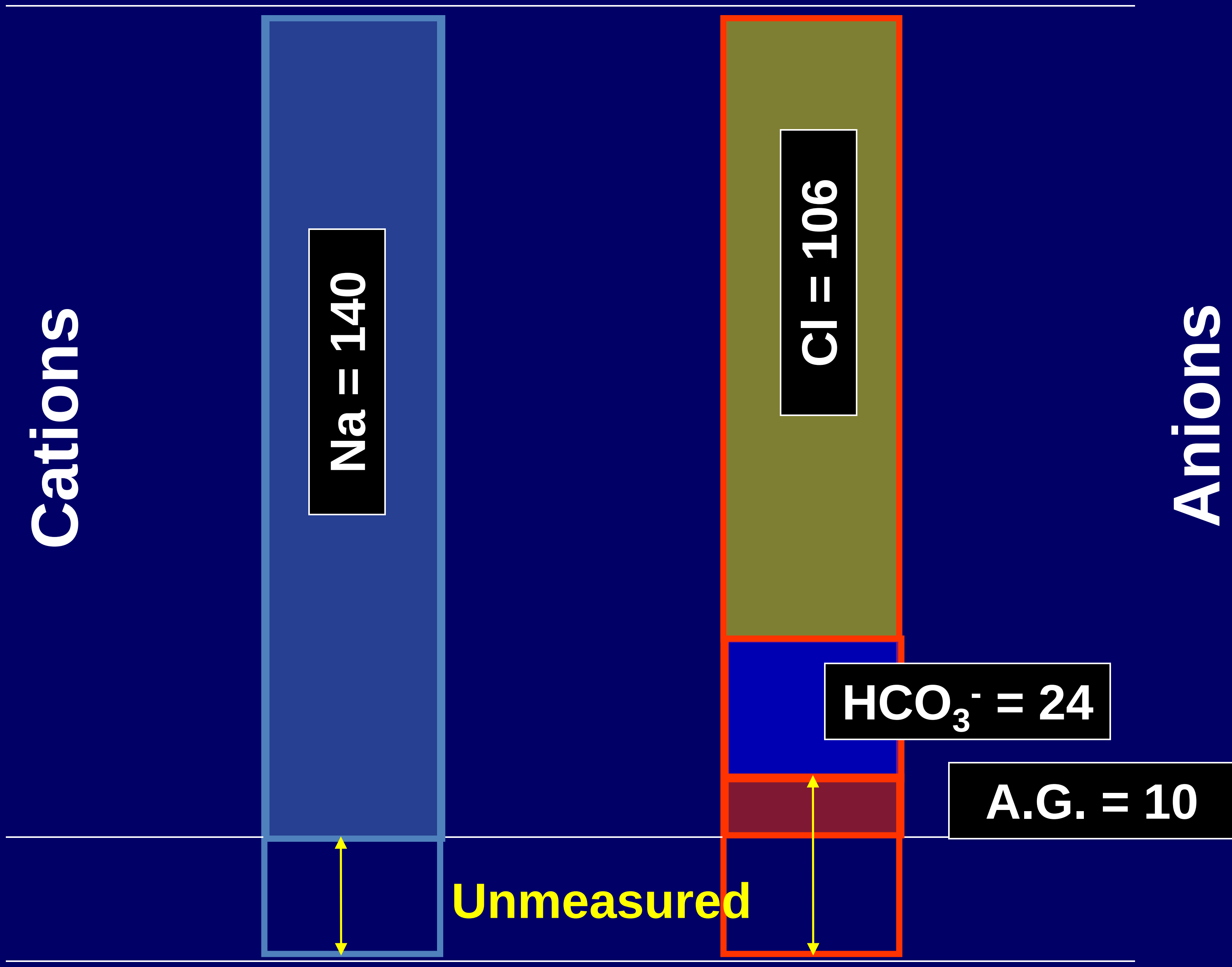
Mixed Respiratory & Metabolic Acidoses

	Health	Emphysema	Diarrhea
pH	7.40	7.32	7.10
PCO_2	40	80	80
HCO_3^-	24	40	24

Triple Acid-Base Disorders

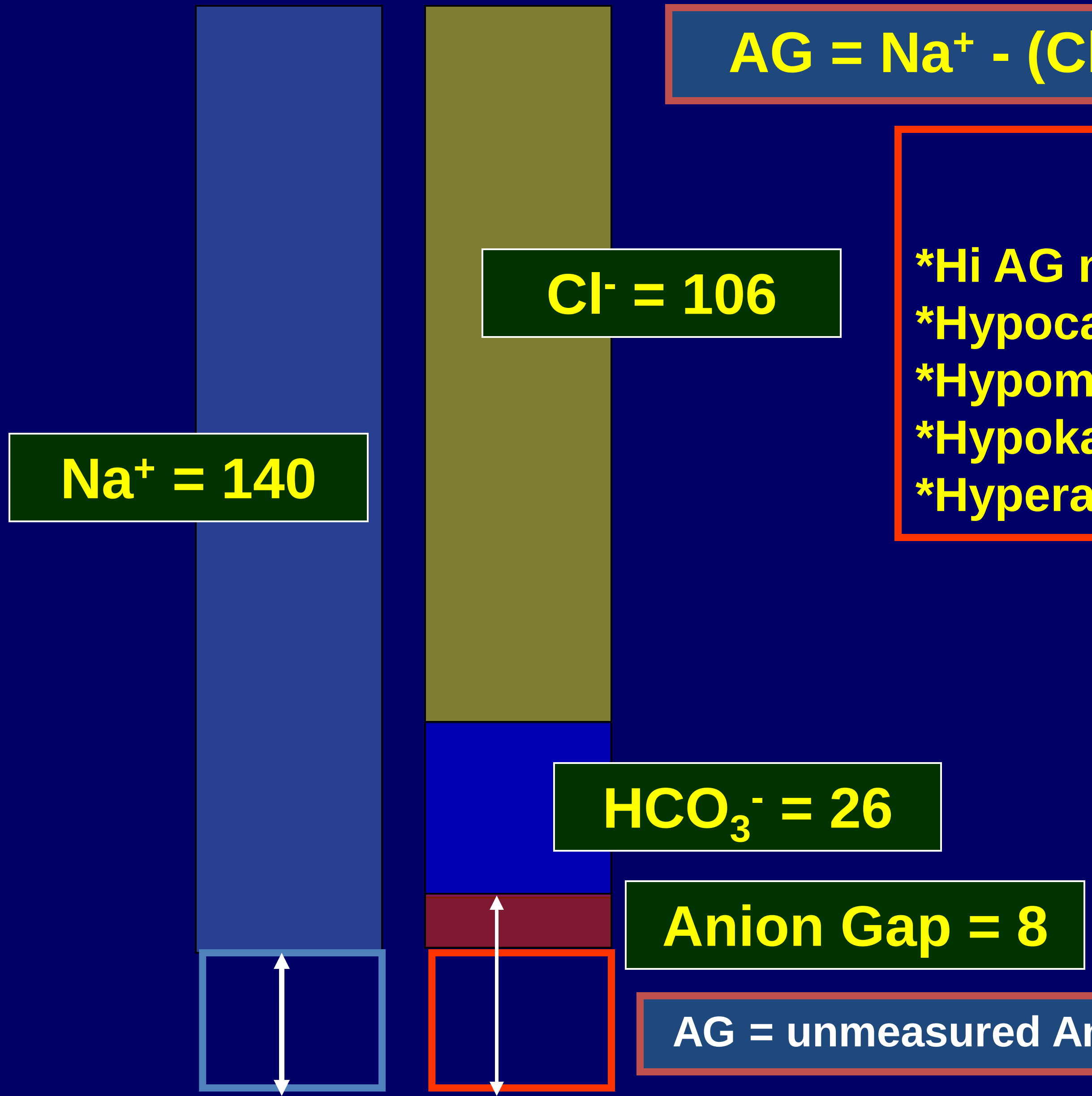
	Health	NG suction	Septic Shock	Endotoxemia
pH	7.40	7.49	7.14	7.44
PCO_2	40	44	24	12
HCO_3^-	24	32	8	8
Anion Gap	9	11	33	35

Cations & Anions of ECF : Electrical Neutrality



Anion Gap = Measured Cations - Measured Anion

$AG = Na^+ - (Cl^- + HCO_3^-) = 3 - 11$



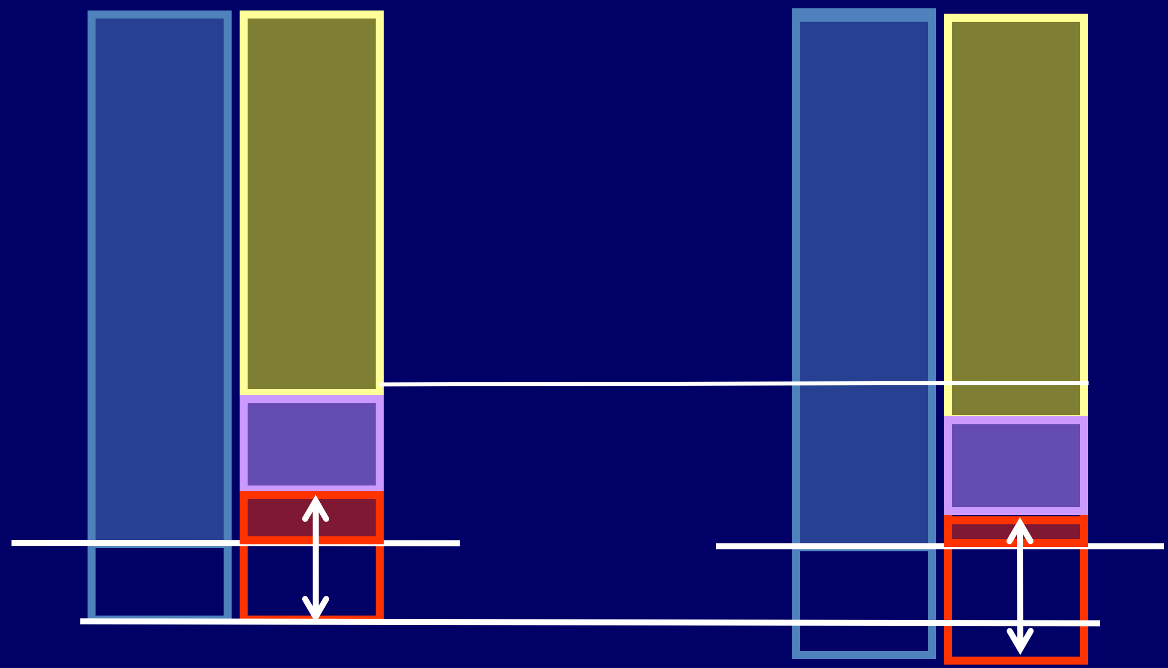
↑ AG:

*Hi AG met. Acidosis,
*Hypocalcemia,
*Hypomagnesemia,
*Hypokalemia,
*Hyperalbuminemia

↓ AG:

*Hypercalcemia,
*Hypermagnesemia,
*Hyperkalemia,
*Hypoalbuminemia

AG = unmeasured Anions - unmeasured cations



	Normal	↑ Unmeasured Cation
Na	140	140
Cl	106	114
HCO_3	24	24
Anion Gap	10	2
U. Cations	12	20

Total unmeasured Anions = 22

6-step approach

- **Step 1:** Assess the internal consistency of the values using the Henderseon-Hassel bach equation:

$$[H+] = \frac{24(PaCO_2)}{[HCO_3-]}$$

$$pH = pK + \log([HCO_3^-)/[\alpha CO_2]) \quad \textit{(Hasselbalch, 1916)}$$

$$\therefore \; pH = 6.100 + \log([HCO_3^-]/[0.03PCO_2])$$

And since log 0.03 = -1.5228787

$$\therefore \; pH = 7.622 + \log([HCO_3^-]/PCO_2)$$

Calculate the anion gap

- Calculate the anion gap (if a metabolic acidosis exists): AG= [Na+]-([Cl-] + [HCO_3-]) =12 ± 2
- A normal anion gap is approximately 12 meq/L.
- the "normal" anion gap in patients with hypoalbuminemia is about 2.5 meq/L lower for each 1 gm/dL decrease in the plasma albumin concentration (for example, a patient with a plasma albumin of 2.0 gm/dL would be approximately 7 meq/L.)
- If the anion gap is elevated, consider calculating the osmolal gap = measured OSM – (2[Na+] - glucose/18 – BUN/2.8: should be < 10

If an increased anion gap is present, assess the relationship between the increase in the anion gap and the decrease in [HCO_3-]

- ΔAG/Δ[HCO_3-] *should be between 1.0 and 2.0 if an uncomplicated anion gap metabolic acidosis is present*
- If ΔAG/Δ[HCO_3-] < 1.0, then a concurrent non-anion gap metabolic acidosis is likely to be present.
- If ΔAG/Δ[HCO_3-] > 2.0, then a concurrent metabolic alkalosis is likely to be present.

Example Case

- An 84-year-old female nursing home resident is brought to the emergency department due to lethargy. At the nursing home, she was found to have a blood pressure of 85/60 mmHg, heart rate 101 beats/min, temperature 37.8°C. Laboratory data are obtained: sodium 137 meq/L, potassium 2.8 meq/L, HCO_3^- 8 meq/L, chloride 117 meq/L, BUN 17 mg/dL, creatinine 0.9 mg/dL. An arterial blood gas shows PaO_2 80 mmHg, PCO_2 24 mmHg, pH 7.29. Her urine analysis is clear and has a pH of 4.5. What is the acid-base disorder?
  - A. Anion-gap metabolic acidosis
  - B. Non-anion gap metabolic acidosis
  - C. Non-anion-gap metabolic acidosis and respiratory alkalosis
  - D. Respiratory acidosis

- What is the most likely cause of the acid-base disorder of the patient in the preceding scenario?
  - A. Diarrhea
  - B. Diuretic use
  - C. Hyperacute renal failure
  - D. Hypoaldosteronism
  - E. Proximal renal tubular acidosis

Case 1a

pH	7.15
HCO_3^- mEq/L	6
PCO_2 mmHg	18
Cl^- mEq/L	114
Na^+ mEq/L	135
K^+ mEq/L	4.5

Case 1b

pH	7.15	↓
HCO_3^- mEq/L	6	↓
PCO_2 mmHg	18	↓
Cl^- mEq/L	114	↔
Na^+ mEq/L	135	↔
K^+ mEq/L	4.5	↔
AG mEq/L	15	↔

AG = 135 – (114 + 6) = 15

Acidosis

Metabolic

Normal Anion Gap Metabolic Acidosis

Case 2a

pH	7.08
HCO_3^- mEq/L	10
PCO_2 mmHg	35
Cl^- mEq/L	116
Na^+ mEq/L	140
K^+ mEq/L	4.5

Case 2b

pH	7.08	↓	**Acidosis**
HCO_3^- mEq/L	10	↓	**Metabolic**
PCO_2 mmHg	35	↔	

$$\text{Expected } PCO_2 = 1.5 \times [HC0_3^-] + 8$$
$$= 1.5 \times 10 + 8 = 23 \text{ mmHg}$$

Actual PCO_2 > Expected PCO_2 = Respiratory Acidosis

=Normal AG Met. Acidosis Associated with Resp. Acidosis

Case 2c

pH	7.08	↓	**Acidosis**
HCO_3^- mEq/L	10	↓	**Metabolic**
PCO_2 mmHg	35	↔	
Cl^- mEq/L	116	↔	
Na^+ mEq/L	140	↔	
K^+ mEq/L	4.5	↔	
AG mEq/L	14	↔	

$AG = 140 – (116 + 10) = 14$

Normal Anion Gap Metabolic Acidosis

Case 2d

- the patient has a respiratory acidosis which might represent **"tiring out"** of the patient's respiration and impairment of his ability to compensate for the metabolic acidosis. It could also be a clue to a coincident pulmonary process.
- ***The rising PCO2is a dangerous sign in metabolic acidosis, because further increase in the PCO2 could lead to a precipitous fall in pH.***

Case 3a

pH	7.49
HCO_3^- mEq/L	35
PCO_2 mmHg	48
AG mEq/L	16

Case 3b

pH	7.49	↑	**Alkalosis**
HCO_3^- mEq/L	35	↑	**Metabolic**
PCO_2 mmHg	48	↑	
AG mEq/L	16	↔	

Metabolic Alkalosis

Case 3c

pH	7.49	↑	**Alkalosis**
HCO_3^- mEq/L	35	↑	**Metabolic**
PCO_2 mmHg	48	↑	
AG mEq/L	16	↔	**AG is normal**

Expected PCO_2 = 40 + 0.7 X (measured HCO_3^- - normal HCO_3^-)

= 40+0.7X(35-24) = 47.7 mmHg ; similar to actual

Simple Metabolic Alkalosis

Case 4a

pH	7.68
HCO_3^- mEq/L	40
PCO_2 mmHg	35
AG mEq/L	14

Case 4b

pH	7.68	↑	**Alkalosis**
HCO_3^- mEq/L	40	↑	**Metabolic**
PCO_2 mmHg	35	↔	
AG mEq/L	14	↔	**AG is normal**

Expected PCO_2 = 40 + 0.7 X (measured HCO_3^- - normal HCO_3^-)
= 40+0.7X(40-24) = 51.2 mmHg ; > actual =
Associated Resiratory Alkalosis

Metabolic Alkalosis plus Respiratory Alkalosis

Case 4c

- There are two distinct acid-base disorders present, each with its own set of potential causes. The patient has a metabolic alkalosis secondary to one or more of the known causes ***plus a respiratory alkalosis.***
- ***The causes* for each disorder should be considered separately**.

Case 5 – Shortness of Breath for 2 weeks – a

pH	7.38
PCO_2 mmHg	70
HCO_3^- mEq/L	40
AG mEq/L	16

Case 5 – Shortness of Breath for 2 weeks – b

pH	7.38	$\leftrightarrow\downarrow$	**Acidosis**
PCO_2 mmHg	70	$\uparrow$	**Respiratory**
HCO_3^- mEq/L	40	$\uparrow$	
AG mEq/L	16	$\leftrightarrow$	**AG is normal**

Increase in HCO_3^- = 3.5 X (measured PCO_2 - normal PCO_2)/10 = 3.5X(70-40)/10 = 10.5 mEp/L ; Expected HCO_3^- = 10.5+24 =34.5; < actual = Associated Metabolic Alkalosis

Respiratory Acidosis plus Metabolic Alkalosis

Case 5 – Shortness of Breath for 2 weeks – c

- There are ***two distinct acid-base disorders present in this patient. Both disorders*** are pathologic - one is not ***compensation for the other, even though*** the pH may be close to normal. In other words, this patient has two processes going on at the same time that tend to ***offset each other: A metabolic alkalosis*** that is secondary to one of the known causes ***plus a respiratory acidosis.***
- ***Causes for each of the two disorders should be considered separately***

Hederson-Hasselbalch Equation

$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

$[H^+] = K_{eq} \times [H_2CO_3]/[HCO_3^-]$

$[H^+] = K \times [\alpha CO_2]/[HCO_3^-]$ *(Henderson, 1909)*

(α = solubility of CO_2 in physiologic solutions = 0.03)

$pH = pK + \log([HCO_3^-)/[\alpha CO_2])$ *(Hasselbalch, 1916)*

$$\therefore \ pH = 6.100 + \log([HCO_3^-]/[0.03PCO_2])$$

And since log 0.03 = -1.5228787

$$\therefore \ pH = 7.622 + \log([HCO_3^-]/PCO_2)$$

Blood Gases Report

Test	Result	Unit	Normal
PH	7.47	7.53	35 – 7.45
PCO2	27.6	mmHg	32 – 45
PO2	53.2	mmHg	75 – 100
HCO3 STD	22.4	Mmol/L	"
O2SAT	90.5	%	
NA	143	Mmol/L	134 -- 155
K	2.46	Mmol/L	3.4 – 5.5

Test	Result	Unit	Norm
PH	7.21	7.13	7.35 – 7.45
PCO2	58.3	mmHg	32 – 45
PO2	38.9	mmHg	75 – 100
HCO3 STD	18.9	Mmol/L	
O2SAT	61.7	%	
NA	136	Mmol/L	134 – 155
K	5.8	Mmol/L	3.4 – 5.5

Test	Result	Unit	Normal
PH	7.4	7.45	7.35 – 7.45
PCO2	38	mmHg	32 – 45
PO2	35	mmHg	75 – 100
HCO3 STD	24	Mmol/L	
O2SAT	70	%	
NA	139	Mmol/L	134 – 155
K	3.9	Mmol/L	3.4 – 5.5

Test	Result	Unit	Normal
PH	7.32	7.40	5 – 7.45
PCO2	27	mmHg	32 – 45
PO2	79	mmHg	75 – 100
HCO3 STD	16	Mmol/L	
O2SAT	95	%	
NA	131	Mmol/L	134 – 155
K	5.8	Mmol/L	3.4 – 5.5

Test	Result	Unit	Normal
PH	7.30	7.29	.35 – 7.45
PCO2	41.8	mmHg	32 – 45
PO2	56.4	mmHg	75 – 100
HCO3 STD	19.5	Mmol/L	
O2SAT	86.5	%	
NA	143	Mmol/L	134 – 155
K	3.24	Mmol/L	3.4 – 5.5

Test	Result	Unit	Normal
PH	7.39	7.49	7.35 – 7.45
PCO2	24.8	mmHg	32 – 45
PO2	101.5	mmHg	75 – 100
HCO3 STD	18.1	Mmol/L	
O2SAT	97.7	%	
NA	147	Mmol/L	134 -- 155
K	2.32	Mmol/L	3.4 – 5.5

مطبعة مستشفى المنصوره الجامعى

Test	Result	Unit	Normal
PH	7.48	7.59	.35 – 7.45
PCO2	22.6	mmHg	32 – 45
PO2	106.0	mmHg	75 – 100
HCO3 STD	20.8	Mmol/L	
O2SAT	98.3	%	
NA	125	Mmol/L	134 -- 155
K	5.8	Mmol/L	3.4 – 5.5

Test	Result	Unit	Normal
PH	7.40	7.55	7.35 – 7.45
PCO2	19.6	mmHg	32 – 45
PO2	70.8	mmHg	75 – 100
HCO3 STD	16.6	Mmol/L	"
O2SAT	94.8	%	
NA	145	Mmol/L	134 -- 155
K	5.5	Mmol/L	3.4 – 5.5

مطبعة مستشفى المنصورة الجامعى

Test	Result	Unit	Normal
PH	7.4	7.56	.35 – 7.45
PCO2	20.5	mmHg	32 – 45
PO2	65.2	mmHg	75 – 100
HCO3 STD	17.6	Mmol/L	
O2SAT	93.8	%	
NA	146	Mmol/L	134 – 155
K	3.38	Mmol/L	3.4 – 5.5

Patient ID

Measured 37°

pH	7.472 ↑		
pCO_2	79.6 ↑	mmHg	
pO_2	16.2 ↓	mmHg	
Na+	133 ↓	mmol/L	
K+	2.11 ↓	mmol/L	
Ca++	1.06 ↓	mmol/L	
Hct	49	%	

↑,↓ = outside ref. range

7.48

Calculated Data

HCO_3 act	56.9	mmol/L
HCO_3 std	49.3	mmol/L
BE(ecf)	---.-	mmol/L
BE(B)	26.3	mmol/L
$ctCO_2$	59.3	mmol/L
O_2 SAT	22.8	%
O_2 CT	5.3	mL/dL

THANK YOU